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AIRFIELD MARKING PAINTS - A STATE-OF-THE-ART REPORT.(U)

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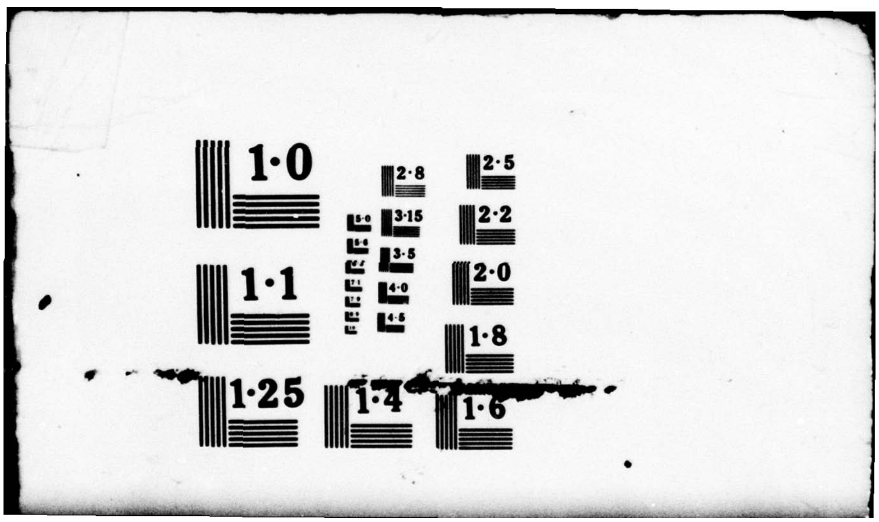
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A state-of-the-art summary has been prepared on the subject of airfield marking paints. Information is presented on the composition of such paints, federal specifications, available test methods, reflectorization methods, deterioration mechanisms, skid-resistance relationships, surface preparations, application requirements, and alternative marking systems. Information on traffic paints was used where it was relevant. A summary of recommended airfield marking practices was prepared to provide practical information to people responsible for airfield marking.

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CONTENTS

INTRODUCTION

The Federal Aviation Administration (FAA) is responsible for the promotion, regulation, and safety of civil aviation and for the development and operation of a common system of air navigation and air traffic control facilities which provide for the safe and efficient use of airspace by both civil and military aircraft. The landing of aircraft is the most difficult part of its operation. A readily visible and recognizable pattern of standard runway stripes and other markings is vital to aircraft safety. These markings are subject to accelerated deterioration under severe environmental and service conditions. Thus, any marking program must include (1) efficient application and maintenance to minimize runway shut down, (2) economical materials and practices that conform to health, safety, and environmental restrictions, and (3) minimal skidding and other safety hazards.

The information presented in this report is not intended to be a comprehensive bibliography on the subject of airfield marking paints, but rather a summary in a simplified form of the important data necessary to establish an effective airfield marking maintenance program. More detailed information on specific items discussed can be obtained from the referenced original sources. A National Technical Information Service bibliography with abstracts on highway markings (Ref 1) covers the period from 1964 to April 1977. A state-of-the-art survey on roadway delineation systems (Ref 2) is also available. The present investigation consisted of (1) a computer search and review of the literature and (2) contacts and discussions with marking paint suppliers, appropriate governmental agencies, marking paint applicators, and airfield operators.

RUNWAY MARKING PATTERNS

Numerous standards (Ref 3-6) for marking and lighting configurations and equipment for airfields are available, including those of the FAA, the military services, the North Atlantic Treaty Organization (NATO), the Southeast Asia Treaty Organization (SEATO), the Central Treaty Organization (CENTO), the International Civil Aviation Organization (ICAO), and the Air Standardization Coordinating Committee (ASCC). Rather than competing with each other, these standards were prepared to complement each other by establishing a general uniformity.

Despite attempts to improve marking patterns (Ref 7, 8, 9), those currently in use seem to be best suited for the situations. Thus, in a test (Ref 5) of 10-foot maximum width diamonds with 75-foot length and spacing against the United States standard centerline (3-foot-wide stripe with a 120-foot length and 80-foot gaps), the standard system was judged to be superior in providing guidance information. The one exception was that, due to the larger painted area, the diamond pattern centerline could be seen farther away. The complex shape, however, involves considerable additional time and money for application.

MARKING PAINTS

Use on Airfields and Roadways

Airfield and roadway marking paints are related to each other in that they perform similar (marking) functions on pavements and, quite frequently, have similar compositions and are made by the same suppliers. However, they do have different physical requirements (e.g., drying time) and are subject to different operational conditions (e.g., traffic) that cause them to deteriorate differently. Because traffic paints receive much greater use than airfield paints, many more studies have been conducted on them. Thus, while both types of paint will be discussed together at times in order to utilize all available information, their basic differences should not be forgotten.

Roadway marking paints, commonly called traffic paints, receive large amounts of vehicular traffic (especially on crosswalks) that cause the markings to deteriorate by chipping (Ref 10-12). Airfield marking paints, on the other hand, tend to deteriorate by being obscured by rubber from aircraft tires in touch-down areas and by the action of natural forces (e.g., sunlight) in areas where they receive little or no traffic. Because roadway marking usually requires the closure of traffic lanes, a quick-drying paint is required to minimize the closure time. Reduction in drying time is frequently accompanied by a reduction in paint flexibility which, as will be discussed later, adversely affects paint performance. On the other hand, runways are usually temporarily closed during a time of light usage and remain so until all marking operations have been completed. Thus, the drying time is not so critical. Because of these differences, many airfield marking paints are not satisfactory for highway marking use (Ref 13).

Composition

All paints used for pavement marking have three basic component parts: pigment, volatile vehicle (organic solvent or water), and nonvolatile vehicle (resin that forms a continuous film on curing).

White marking paints for runways utilize nonchalking titanium dioxide (rutile) as their primary pigment to provide opacity and reflectance. Calcium carbonate and silicates are used as secondary pigments. Lead chromate (chrome yellow) has long been used for yellow marking paints (used on taxiways), but because of a health hazard, it may be replaced by a less toxic pigment (i.e., without chromium) if a suitable one can be found.

Organic solvents that comprise the volatile vehicle portion of most paints evaporate into the atmosphere as the paints dry. Air pollution control legislation limits the amounts of those compounds that are considered to be highly photochemically reactive. More recently, all organic solvents are being considered photochemically reactive so that the total amount of organic solvent in paints may be limited. Such thinking has accelerated the development of water-emulsion (latex) marking paints and other paints that contain relatively small amounts of organic solvents.

Most of the solvent-based marking paints marketed today have a nonvolatile vehicle (resin) that is a modified drying oil, and so they cure by air oxidation of the drying oil after evaporation of the solvents. Oxidation of the paint resin continues upon prolonged weathering to convert its polymeric structure from a two-dimensional to a three-dimensional form, thereby reducing its flexibility. Alkyds are by far the most commonly used type of modified drying oil paint. Oleoresinous phenol varnish paint is a less commonly used modified drying oil marking paint.

The flexibility (sometimes determined as percent elongation) of such marking paints is directly related to oil length, which is defined (Ref 14) as "gallons of oil reacted with 100 pounds of resin;" the curing time is inversely related. Thus, short oil formulations dry more rapidly than long oil formulations, and they form a harder, less flexible film; long oil formulations, conversely, dry more slowly, but have greater flexibility and better exterior weathering. For alkyd marking paints, the oil length is best defined in terms of percentages of phthalic anhydride. Table 1 lists the criteria for short, medium, and long oil length.

In order to obtain the required flexibility from modified drying oil marking paints, it has been suggested (Ref 17) that alkyd formulations have a maximum phthalic anhydride content of 32% and oleoresinous phenolic varnish formulations have an oil length between 30 and 35. These types of modified drying oil paints wet pavement surfaces extremely well so that good bonding can be achieved. Also, the organic solvent in their formulations permits these paints to "bite" into asphaltic surfaces, but at the same time gives rise to the possibility of bleeding of asphalt into the paint.

Chlorinated rubber is sometimes added to alkyd or oleoresinous phenolic varnish marking paints to reduce curing time. This is more important for traffic than airfield marking paints. It should be

noted that even with the simultaneous addition of a plasticizer, such as chlorinated paraffin or chlorinated biphenyl, chlorinated rubber generally decreases paint flexibility.

Most water-emulsion (latex) marking paints marketed today contain acrylic or vinyl-acrylic resins. These resins are dispersed in a water emulsion rather than being dissolved in an organic solvent. Films of water-emulsion paints cure by coalescing of the emulsified resin particles as the water evaporates. They generally cure slower than do modified drying oil paints, especially in cold (below 50F) or damp weather. Water-emulsion marking paints have excellent flexibility, but limited durability under heavy traffic. Thus, they are seldom recommended for traffic paints (Ref 18, 19), but serve quite satisfactorily as runway marking paints. Water-emulsion paints wet surfaces relatively poorly and, thus, are more demanding of a higher level of surface preparation for application than are marking paints containing drying oils.

Specifications

Many states have their own specifications for highway marking paints. Four federal specification marking paints are available for use on asphaltic and portland cement concrete runways. These are listed in Table 2, along with some of their important properties for comparison purposes. Most of these are available in both white and yellow. All of the white and yellow paints can be reflectorized by dropping glass spheres or reflectorized granules into the wet paint.

Paint produced in accordance with Federal Specification TT-P-85 and reflectorized with glass spheres has long been used on airfield pavements. The spreading rate of 105 ±5 sq ft/gal corresponds to about 15 mils wet film thickness, which is appropriate for accepting glass spheres (Federal Specification TT-B-1325), and about 7-1/2 mils dry film thickness. The specification gives the manufacturer latitude in the selection of resin and other materials as long as the paint meets all the performance requirements listed. Alkyd formulations are the ones most frequently used in this specification, but oleoresinous phenolic varnish formulations are also available.

Federal Specification TT-P-1952 produces a much newer water-emulsion marking paint that is finding increased use, particularly on asphaltic pavements because (1) it does not contain appreciable amounts of photochemically reactive solvents, (2) it is less susceptible to asphalt bleeding, and (3) it is less susceptive to edge cracking because of its good flexibility. The specified spreading rate (100 to 150 sq ft/gal) is rather broad. It should be remembered that such latex paints are relatively slow drying, especially at temperatures below 50F and high humidities, when compared to paints conforming to TT-P-85.

Paint produced in accordance with Federal Specification TT-P-110 is black and nonreflectorized for marking or obliterating markings

on runways and highways. It is available in two types: I, conventional, and II, fast drying. As with TT-P-85, the manufacturer is given latitude in the selection of resin and other materials as long as the paint meets all the performance requirements listed. Type I is most commonly alkyd, and Type II is most commonly chlorinated rubber-alkyd. When used for marking, it is spread at a wet film thickness of 15 mils. The paint is used less today for obliterating markings, because such obliterated markings are more confusing to pilots than original marking removal with high-pressure water blasting.

Federal Specification TT-P-115 describes a white or yellow highway marking paint available in three types that has been successfully used on airfield pavements. Type I (alkyd) is the slowest drying and the most appropriate for airfield pavements. Type II (vinyl toluene-butadiene), which is intermediate in drying, is seldom used today. Type III (chlorinated rubber-alkyd) is more appropriate for highways. It is the fastest drying, so it tends to be less flexible and more brittle. All three types are spread at a wet film thickness of 15 mils.

In addition to the four above specifications, Federal Specification TT-P-87 covers a traffic paint (white or yellow) that is premixed with glass spheres; additional spheres can be added after application. The premixed spheres are exposed only after loss of the covering paint by tire abrasion; thus, the paint is intended for use on roadways (Ref 20), not airfield runways.

Canadian Government Specification 1-GP-149 covers a reflectorized alkyd (white or yellow) traffic paint to which 5 pounds of glass spheres are added for each gallon of paint before application. The mixture is suitable for marking at a rate of 150 sq ft/gal.

The volumes of marking paints sold by the General Services Administration (GSA) to federal agencies in 1976, 1977, and 1978 are listed in Table 3. It is estimated by GSA that sales of TT-P-1952 in 1979 may be as high as 300,000 gallons with a significant reduction in the sales of TT-P-85 because of the air pollution problem involved. GSA sells both paints at the same price: $21 for a 5-gallon can at the time of publication of this report. Paint companies that sell to civil airports have found that the sales of TT-P-1952 have been increasing with a corresponding decrease in TT-P-85. Price per gallon was relatively constant for 1976 and 1977 but rose significantly in 1978 because of raw material price increases associated with the petroleum shortage.

Testing

Each of the specification marking paints of Table 1 can be checked for conformance to the listed requirements using standard testing procedures referenced in the specification. Referenced test procedures are usually those of Federal Test Method Standard Number 141a (Ref 21) or the American Society for Testing and Materials (ASTM) (Ref 22).

Proprietary (nonspecification) paints can also be tested by these procedures to determine some of their physical or chemical properties. ASTM also lists a number of field tests for traffic paints. Special ASTM laboratory and field tests for traffic paints are listed in Table 4. Procedures are available for preparing the infrared spectra of paint resins (nonvolatile vehicles) and solvents (volatile vehicles) (Ref 23, 24). Equipment for nondispersive x-ray spectrometric analysis and an ARL microprobe can be used to determine the properties of paint pigments (Ref 23).

The identity of a weathered marking paint can be determined by spectrographic analysis (Ref 25) or by test tube size experiments (Ref 26). A simple pyrolysis test (Ref 27) can be used for detecting alkyd resin in traffic paint. A flame coloration test (Ref 26) is used for detecting chlorinated rubber in traffic paints.

A complete analysis of a paint for conformance to the requirements of TT-P-85 or TT-P-1952 is quite expensive. However, if a full analysis of a large batch of these paints cannot be made, flexibility, weight per gallon, viscosity, total solids, and nonvolatile vehicle can be tested at relatively little cost. Because flexibility is so important in marking paints, they should always meet specification flexibility requirements.

No accelerated testing procedure is currently available for determining wear of marking paints. Simulated traffic wheels, Taber abrasion tests (Method 6192, Ref 21), falling sand tests (Method 6191, Ref 21 and D-968, Ref 22), and other methods (Ref 28) have been tried, but the results correlated poorly with field results. Poor correlation is probably because such laboratory tests determine abrasion or erosion,* while traffic paints fail by chipping** (Ref 10, 28, 29).

Flexibility of traffic paint is usually determined qualitatively by bending a thin painted panel over a cylindrical mandrel (Method 6221, Ref 21) and checking for paint cracking. Use of a conical mandrel, however, permits a quantitative measure of paint elongation. A free film method (Method 6222, Ref 21 or D-522, Ref 22) can also be used for determining paint elongation. This latter system has been shown (Ref 30) to be quite precise and to correlate well with field testing. Tensile strength can also be determined by the free film method.

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*Abrasion or erosion condition is defined in ASTM Designition D821 as the "more or less graduation surface disappearance, thinning of the film, and exposure of the substrate because of abrasion, erosion, or combinations of both."

**Chipping is defined in ASTM Designation D913 as "actual detachment of entire sections of the film, usually in small pieces, either from its substrate or from paint previously applied" and "is usually characterized by sharp edges and definite demarkation of the bare area."

PAINTED MARKINGS

Deterioration

Deterioration of marking paints and underlying pavements may result from (1) deficiencies in the paint, (2) deficiencies in the pavement, (3) improper surface preparation, (4) improper coating application, (5) environmental factors, (6) service factors, or (7) a combination of these factors. The nature and rate of deterioration will vary with each case. There are, however, specific types of deterioration that occur most frequently with well-formulated and correctly applied paints on different substrates.

On heavily trafficked roadways chipping is the most common form of paint deterioration (Ref 10-12); however, abrasion or erosion occur to a significant extent. Chipping is enhanced by the presence of glass spheres (Ref 31). Deterioration occurs quite differently on airfield markings because they receive lesser amounts and different kinds of traffic. The deposition of rubber by touch-down of aircraft on runway paints is one of the chief contributors to deterioration of centerline markings, particularly on runways serving heavy aircraft. This may obscure markings to the extent that the rubber must be removed or the marking reapplied. Chipping also occurs (Ref 27), but there is very little abrasion or erosion damage. Sideline runway markings that receive very little or no traffic generally deteriorate from environmental factors.

Special problems exist with asphaltic pavements that do not exist with portland cement concrete pavements because of the much greater chemical inertness and strength of the latter. Asphalt is quite soluble in most organic solvents. Thus, discoloration of markings may occur if the asphalt is dissolved by solvent and redeposited upon the marking. The solvent may be introduced by accidental contamination (for example, spillage of fuel or cleaner) or as a component of the paint. When excessively strong solvents are present in the paint, the discoloration (bleeding*) occurs shortly after paint application. Bituminous joint sealing materials on portland cement concrete pavements may also bleed up through marking paints (Ref 11). Where there are low areas (commonly called "bird baths") in the pavement that collect rain-water, asphalt from recently paved or sealed pavements can be spread by the water onto painted markings. Coal tar seals have been used to minimize solvent deterioration of asphaltic pavements, but concern about carcinogenic compounds in coal tar may limit its use on pavements.

Runway marking paints must be sufficiently flexible to expand and contract with the pavements to which they are bonded and to absorb

*Bleeding is defined in ASTM Designation D868 as "that condition of discoloration manifested in traffic paint when applied to tar or asphaltic-type roads."

the stress to the paint film that occurs from paint contraction during drying and from weathering. Because of differential thermal expansion and contraction, white paints present more problems than yellow paints, and asphaltic pavements present more problems than portland cement concrete pavements.

Studies at the Civil Engineering Laboratory (CEL) (Ref 27, 32-36) have shown that deterioration of paints along painted stripes occurs by the following mechanisms:

1. Marking paint contracts significantly on curing and sets up a stress between itself and the substrate. Both paint and pavement continue to harden, becoming more rigid with time.

2. Daily differential expansion and contraction between the painted marking (together with adhering substrate) and the substrate adjacent to the marking add to this strain. Griffith and Puzinauskas (Ref 37) found edge cracking of sand-asphalt pavement surfaces was eliminated when their test paints were pigmented so heavily with carbon black that they were black in color.

3. Cracking of the paint occurs if the stress caused by the paint contraction becomes greater than the cohesive forces in the paint. Portland cement concrete pavements generally suffer no adverse effects, but asphaltic pavements may suffer surface damage from paint contraction. On slurry-sealed asphaltic pavements, the relatively weak bond of the slurry seal to the pavement is usually broken before paint cracking occurs or while paint cracking is occurring. Separation and curling of the slurry seal from the pavement is initiated along the cracked edges (Figure 1).

4. Penetration of rainwater under lifted edges of paint or slurry seal promotes further loss of bonding. Collection of rainwater in areas of painted markings may significantly increase the rate of chemical decomposition of the paint.

5. Reduced flexibility or increased contraction of the paint film tends to accelerate deterioration associated with marking paints because of the resultant greater stress between the paint and substrate. A buildup of several coats of paint increases the stress between the initial coat and its underlying substrate.

6. Asphalt is quite soluble in hydrocarbon and other organic solvents; therefore, variations in paint formulation that permit greater solvent action promote deterioration. Thus, high boiling solvents (or thinners) should be avoided since they permit more time for the solvent to penetrate the asphalt before evaporating.

7. Ultraviolet radiation contributes to the deterioration of paint binders. Thus, tropical locations have the disadvantage of

high ultraviolet radiation in addition to heavy rainfall. Remote tropical locations generally have additional problems associated with supply, storage, and proper application of marking paints.

Reflectorization

Glass spheres (beads) are used on most marking paints to reflect light from the aircraft or car back to the pilot or driver, thus making the markings much more visible at night. During wet weather, however, a water film can cover these spheres, thus rendering the reflectivity ineffective (Ref 38).

Glass spheres used to reflectorize pavement marking paints are made from different qualities of glass depending upon the desired level of index of refraction. Table 5 gives the relative indexes of refraction and compositions for the various types of spherical glass beads listed under Federal Specification TT-B-1325. Canadian Government Specification 1-GP-149 calls for glass spheres with a minimum refractive index of 1.50. Beads used for marking highways may be of a significantly lower quality than those for airfield marking.

The method of bead manufacture results in production of beads of a mixed gradation of sizes and slight variation in shape. Gradation requirements (sieve size range) are also listed in TT-B-1325. State highway department specifications for gradation size of drop-on glass beads are somewhat different (Ref 39). A State Highway Commission of Kansas study (Ref 10) of bead retro-reflectivity showed that non-uniformity of beads does not always result in adverse effects. Beads with only a few bubbles and impurities were almost as reflective as those without flaws. Somewhat out-of-round beads were about as reflective as round ones, but very oblong ones were not. Fragments and stringers of glass, beads with knobs, or fused-together beads generally had less reflectivity.

Because the glass from which beads are made is very hydroscopic, the beads tend to absorb moisture from the atmosphere and lose their free-flowing characteristics. Should beads become caked together, they may be hard to separate without damaging them. Damp beads when dropped into paint might fall as groups rather than as individual beads or might clog the dispenser. Thus, they should always be maintained in a dry condition.

It is generally agreed that the best bead size for optimum optical performance depends upon the wet film thickness of the paint into which it is being dropped. Optical properties and bead retention appear to be optimum if about 60% of the bead is covered with paint (Ref 39, 40). While it was once believed that the bottom of a bead should not touch an asphaltic pavement because it would reflect the pavement color, this is not the case (Ref 10).

It is standard practice to apply glass beads to roadway paints at a rate of 6 lb/gal of paint* (e.g., TT-P-115) and to airfield marking paints (e.g., TT-P-85 and TT-P-1952) at a rate of 10 lb/gal. Most roadway and airfield marking paints are applied at a wet film thickness of about 15 mils. This thickness is appropriate for the bead gradation specified in TT-B-1325. The Kansas study (Ref 10) reports much savings on roadways by applying the paint at a 10 mils wet film thickness and dropping the beads on at a rate of 4 lb/gal with no lessening of optical performance. It should be noted that it is difficult to accurately control the rate of bead application (Ref 41) because of differences in speed of striping vehicles, road roughness, moisture, wind, superelevation, and bead characteristics.

A field test was run by the State of New York (Ref 42) to determine whether the increased cost of intermediate index of refraction beads as compared to low index beads (see Table 5) could be justified on roadways on the basis of increased night visibility. On the basis of photometer readings and bead counts on asphaltic and portland cement concrete pavements, it was found that (1) although the intermediate index beads initially provided greater reflectance on portland cement concrete pavement, that after 8 weeks, the reflectance had declined to where no differences could be noted and (2) although on the asphaltic concrete pavement the intermediate index beads consistently measured greater reflectance, visually the difference was hardly noticeable. It was, therefore, concluded that the additional cost of about $0.02/lb could not be justified.

A more recent development is the "floating bead." This bead, which is more uniform in gradation, has a surface coating that causes it to float in the wet paint to its fullest extent. Field testing of these beads (Ref 43-46) showed them to be as good as or better than other beads in visibility and reflectivity.

Loss of reflectance from reflectorized traffic paint is mainly from paint chipping (Ref 46). The limited night reflectance of some newly painted stripes was shown (Ref 10) to have resulted from overspray of paint onto beads. This was attributed to excessive spray pressure or wind. In another case (Ref 10), loss of daylight reflectance on a city pavement was related to dust and grime covering the stripes. A thin film of water covering the beads may have relatively minor influence on reflectance (Ref 39), but total immersion will effectively blank them out (Ref 10). Loss of reflectance from shadowing of one bead by another is reduced by using one size of bead in a paint film that covers 60% of the bead diameter (Ref 10). In an unusual, but interesting case (Ref 10), loss of beads was attributed to mold growth loosening the beads from the paint film.

TT-P-115 permits the use of reflectorized granules conforming to TT-G-490, Type I (high intensity) rather than beads conforming to TT-B-1325, Type III (high index), Gradation A (Coarse - Drop On); however, they are seldom used today.

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*Sometimes 4 lb/gal are premixed with the paint, and an additional 2 lb/gal are later dropped onto it.

PAINTING

Surface Preparation

As with all painting operations, the preparation of the surface to be painted is as important as the paint application itself. On all new pavement surfaces, the pavement must be satisfactorily cured before the paint is applied. This requires at least 2 weeks for portland cement concrete and at least 3 weeks for asphaltic pavements or slurry seals.

All dirt and loose materials that would reduce the bonding of the paint to the pavement must be removed by sweeping. Oils must be removed by washing with trisodium phosphate or other detergents, rinsing with water, and allowing the area to dry before painting. In addition to cleanliness, paint adhesion is also related to pavement surface texture. Because asphaltic pavements have more texture than portland cement concrete pavements, paint usually bonds better to them. A surface preparation study (Ref 47) on a portland cement concrete pavement showed that light sandblasting increased paint life substantially, compared to instances where the pavement was broomed or blown with compressed air. Thus, paints have been found (Ref 48) to fail more rapidly on smooth, rather than textured, pavements. Sandblasting has also been found (Ref 49) to increase wet-night visibility of stripes.

When repainting old markings, all old loose paint must be removed (see the section in this document on rubber and paint removal). Any remaining paint must be adhering firmly and be free of loose surface chalk. This is especially true with latex marking paints (e.g., TT-P-1952) which do not wet as well as alkyd paints (e.g., TT-P-85). Latex (e.g., acrylic) paint can be applied over alkyd paint or alkyd paint over latex paint, as long as the old painted surfaces have been properly prepared (Ref 50). After five coats of paint have been applied to a pavement, it is probably best to remove the old marking completely because of accelerated deterioration with multiple coats of paint, reduced skid resistance, and loss of pavement texture.

Application

Markings are usually applied to pavements by spraying. Brushing or rolling oil-based paints (e.g., alkyd) onto asphaltic pavements can cause asphalt to be picked up by the paint by action of the paint solvent on the asphalt. Thus, if brushing or rolling is necessary, the paint should be applied in two coats with the first coat being completely cured before the second is applied. Striping is usually accomplished with self-propelled (Figure 2) or towed equipment that have multiple spray heads; dispensers are located directly behind the spray heads for dropping the glass beads into the wet paint. Numbers and other small markings are manually sprayed with paint

and sprinkled with glass beads. The equipment is always checked for proper operation and metering of paint and beads at specified rates before actual application of markings.

Large quantities of marking paint (over 50 gallons) should be checked for conformance to specification. Also, two 1-quart representative samples of the paint should be retained for later reference, should any problems arise.

Painting of runways can be done by contract or by airport personnel, but in either case the personnel must be very familiar with the equipment and the job requirements. The Air Force has two striping teams that operate out of McClellan Air Force Base located near Sacramento, Calif. The teams schedule a series of military installations (Army, Navy, or Air Force) in a general area and then fly their equipment there to accomplish the work. A survey conducted by the Air Force indicated that their striping teams save about 8% over contracted works.

Air Force Regulation 91-14 (Ref 51) prescribes the responsibilities and procedures for using Air Force mobile teams to mark and remark military airfield and road pavements with truck-mounted 36-inch marking vehicles. A section of this regulation gives details as to the responsibilities of the installation receiving the service, including the surface preparation (mechanical cleaning or water blasting), paint (TT-P-85 and TT-P-1952), operational supplies, and clean-up procedures.

TT-P-1952 is used by the Air Force striping teams on asphaltic pavements to avoid deterioration initiated by edge cracking and on all pavements in California to minimize pollution of the air with photochemically reactive organic compounds. TT-P-85 is used on portland cement concrete pavements, except in California (as previously noted). Both specification paints perform well on edges, but they both have rubber deposition as the chief problem on the centerline. The TT-P-1952 is believed to be a little easier to apply and clean up than the TT-P-85.

Most marking paints are applied at a wet film thickness of about 15 mils, which is appropriate for the gradation of the glass beads dropped in for reflectorization. TT-P-110 and TT-P-115 specify a wet film thickness of 15 mils; TT-P-85 specifies a spreading rate of 105 $\pm$5 sq ft/gal and TT-P-1952, of 100-150 sq ft/gal. The latter spreading rates are consistent with 15-mil wet film thickness if the paints are not thinned. The 15-mil wet film thickness or a corresponding dry film thickness of about 7 to 8 mils can be easily checked by measuring with a gage the thickness of a test stripe applied across a metal plate (Ref 52, 53, and Methods D1212 and E376 of Reference 21). The spreading rate and/or paint film thickness can also be calculated (Ref 54) from the area painted and the volume of paint used, provided the empty containers are retained for verification purposes. In a study (Ref 55) of the performances of traffic paints applied at wet film thicknesses from 12 to 21 mils, the thicker stripes were more durable, but durability was not directly proportional to

added thickness. It was concluded that wet film thicknesses in excess of 16 mils were not economical. Another study (Ref 28) of the effects of wet film thickness showed an increase in durability and night visibility with increasing thickness in the range from 10 to 20 mils. Thicknesses of 10 mils or less were insufficient for adequate retention of dropped beads. A Kansas study (Ref 10), however, showed good performance and economy at wet film thicknesses of 10 mils with glass beads of appropriate size. It should be noted that the repainting of old stripes accelerates their separation from the pavement because of the increased thickness (Ref 27) and reduces their skid resistance (Ref 56-58); therefore, in these cases, thinner films will have beneficial effects. If such stripes are not to be reflectorized with glass beads and if increased visibility is all that is desired, then a thin cosmetic film will be sufficient.

Paints must be sprayed only during periods of favorable weather conditions. High winds can cause an irregular spray pattern or blow dust onto the wet paint. They can also cause the beads to scatter to areas other than the wet paint. This can be minimized by placing a rubber boot on the bead dispenser that extends to within 1/2 inch of the pavement (Ref 43). Fog will not permit proper paint curing, and low temperatures will also inhibit paint curing. Alkyd and other modified drying oil paints should not be applied below 40F or water-emulsion paints below 50F.

PROBLEMS WITH PAINTED PAVEMENTS

Skid Resistance

Relatively few studies have been conducted on the skid resistance of airfield runways. Thus, between 1969 and 1975 only about 250 civil and military runways worldwide were measured for skid resistance using standard diagonal braked vehicles (Ref 56). By contrast, the United States alone has 500 civil airports with approximately 1,000 runways that serve air carrier jet transports. Obviously the hazards associated with high speed aircraft landing on wet, slippery runways dictate that much more work be undertaken to study the nature and extent of runway slipperiness and to implement preventive or corrective procedures.

Studies have shown (Ref 56-58) that frictional values for painted runway and roadway pavements are directly related to the original pavement texture and the paint thickness. Since asphaltic concrete surfaces are relatively textured (as compared to portland cement concrete surfaces), single applications of paint on them do not result in an appreciable reduction of skid resistance (Ref 57). Multiple coats of paint, however, reduce the surface texture as well as the channels for water drainage. On less-textured portland cement concrete runways, the paint has a significant effect on skid resistance

unless preventive measures are taken (Ref 57). Slipperiness appears to be a minor problem for vehicles on striped roadways, especially when dry, with thermoplastic stripes presenting no more of a problem than conventionally painted stripes (Ref 58).

In order to have sufficient texture for good skid resistance, an asphaltic or portland cement concrete pavement should contain sharp siliceous sand and sharp angular aggregate. Also, the paving process must be such as to retain these materials at the surface. Rolling of asphaltic pavements tends to push them deeper into the pavement. Mechanical vibration of portland cement concrete pavements tends to force large aggregate down and float fine portland cement grout and sand mixture to the pavement surface.

On freshly paved asphaltic surfaces, the sand and aggregate particles are coated with asphalt and, thus, can initially have less skid resistance than later when this surface coating has been lost by traffic friction and natural weathering. On portland cement concrete pavements, the surface areas in the wheel paths can become polished after years of traffic so that they become less skid resistant and less easily bonded by traffic paint.

While the addition of glass beads to marking paints can make them slightly more slippery, the heavy buildup of rubber deposits is the biggest contributor to slipperiness of runways, whether striped or unstriped. Reduced friction on wet areas can lead to hydroplaning. Closely-spaced pavement grooving can alleviate this condition because rubber is not deposited in the grooves to plug the drainage channel and the pattern permits more tire contact for greater friction. The only known adverse effect of pavement grooving on runways is the occasional development of chevron cuts on aircraft tire treads; however, this is not considered a serious problem.

Because of speed, the runway area that is probably the most likely to have hydroplaning or other skidding problems for aircraft is where tires first touch-down. Unfortunately, this area usually has the heaviest rubber buildup and more runway markings for pilot identification.

Although they should not be taken as currently recommended practices, several procedures can be used to obtain maximum continued skid resistance on wet, painted markings and adjacent areas on airfield runways:

1. When paving runways, optimum materials (i.e., sharp sand and sharp, angular aggregates) and paving methods should be utilized to obtain a highly textured surface.

2. A new surface treatment, such as grooving, should be done to increase wet pavement resistance and to drain surface water. Low pavement areas that permit water collection should be corrected.

3. All accumulated paint in touch-down and centerline areas should be completely removed from asphaltic and portland cement concrete pavements prior to the fifth remarking. High pressure water blasting can do this without damaging the pavement. Of course, all loose paint should be removed prior to each recoating because contraction of the new paint upon curing and weathering will accelerate the loss of bond.

4. Angular roofing gravel can be dropped along with the glass spheres into the wet paint to help equalize the skid resistance of the marking with that of the adjacent pavement. A study (Ref 57) showed that smaller granules (size no. 28) gave longer lasting results than larger granules (size no. 11). While ground glass mixed into the paint was found (Ref 57) to improve skid resistance initially, it deteriorated rapidly with trafficking. In another study (Ref 13, 59) calcined aluminum oxide and angular glass were found to be the best antiskid additives, and synopal (a calcined calcium carbonate and silicon dioxide) and polypropylene showed some promise.

5. A transverse bar marking pattern would tend to minimize skid resistance differences with adjacent unmarked pavement. Such a pattern might not produce the desired visual delineation and would require special application equipment and procedures.

6. Reduction of the spreading rate for glass spheres could possibly increase the skid resistance slightly.

7. Painted markings and adjacent pavements should be cleaned as frequently as heavy rubber buildup occurs.

Removal of Rubber and Paint

When high speed aircraft touch down on asphaltic or portland cement concrete runways, the frictional heat usually results in devulcanization and baking of the natural rubber from the aircraft tires (Figures 3 and 4) onto the pavement (Ref 13, 56, 60, 61). Heavy buildup of rubber can obscure runway markings, contribute to slipperiness, and cause problems in restriping or resurfacing of the pavement. Thus, the rubber must be removed when any of these items becomes a serious problem. Painted markings must be removed when they are no longer part of the pattern. Also, loose paint must be removed for each remarking, and all paint must be removed for restriping after a thick buildup has occurred.

Most of the systems developed for removal of rubber from runways have also been used for paint removal. Several systems have been used successfully, but they all have their limitations in rubber and paint removal. Because paint is more strongly bonded to pavement than rubber, it is more difficult to remove.

Sand (or other abrasive) blasting is an effective removal method, but the removal rates are low, and, in addition to being costly, the system requires long runway closure times. Exterior abrasive blasting is restricted in many locations because of air pollution by particulates, and it can be expected to be restricted in all locations in the future.

Equipment of different types that remove rubber and paint from pavements by grinding have been successfully used. Removal is not complete, however, without some damage to the pavement surface.

Chemicals have been successfully used in removing rubber and paint from runways, but they are used less today because of possible contamination of watersheds surrounding airports as well as being a health hazard to workers. The chemicals used to soften, dissolve, and/or emulsify the rubber also have potential adverse effects on painted markings (Ref 13). Presently acceptable solvents in the chemical formulation may become unacceptable if stricter regulations on air pollution by organic solvents are enacted.

High pressure water blasting is the most commonly used method of rubber and paint removal today. It is practical, economical, and relatively safe for pavements and the surrounding environment. More precautions must be taken with asphaltic than with portland cement pavements. Different types of nozzles, nozzle stand-offs, dwell times, and pressures are available for use with the water-blasting equipment. Pressures from 5,500 to 7,500 psi are commonly used for rubber and paint removal. In one comparative study (Ref 56), a high pressure waterblast system with a rotating spray bar was found to be equal or superior to other systems tested, but a direct impact system is preferred by some users. Hardened steel cutter wheels can be applied to the painted markings to weaken their bond to the pavement before water blasting (Ref 62). Contracts for runway rubber and paint removal frequently require 95% removal of all visible rubber and 80 to 85% removal of built-up paint at a minimum rate of 10,000 sq ft/hr.

The cost of removing 40,000 to 50,000 sq ft of rubber by water blasting in 1972 (Ref 61) was estimated to be \$0.035 to \$0.0475/sq ft; an estimate in 1975 (Ref 60) for 100,000 sq ft was about \$0.02/sq ft. A 1972 (Ref 61) estimate for removing 100,000 sq ft of paint markings was \$0.06/sq ft. Because alkyd paints bond more strongly to asphaltic and portland cement pavements than do acrylic paints, they are more difficult and more costly to remove by water blasting. Obviously, costs for removal of rubber and paint from runways vary with the amount of materials to be removed, the strength of bonding to the pavement, the equipment being used, and the skill of the operators.

The past use of flame or other heat sources (Ref 10) to remove paint and rubber has been slow, bothersome, and ineffective. More recently (Ref 62), two new methods for burning off painted markings have been developed. In the first, two wide, flat burner heads are tandemly mounted on a simple hand-propelled cart (e.g., golf bag carrier). The forward head burns propane and oxygen, while the rear head floods the heated area with excess oxygen to produce an extremely hot

flame that rapidly combusts the paint stripe without significantly affecting asphaltic or portland cement concrete pavement surfaces. In the second method, a special burner uses many tips to produce a wide propane-oxygen flame with a lower temperature so that follow-up with a mild scarifier is required for complete removal. The second method causes more pavement damage than the first system.

A high pressure jet of air directed at a low angle onto paint stripes was effective in removing paint (Ref 10), but the necessary air supply is not readily available.

ALTERNATIVE MARKING MATERIALS

Numerous research and development studies (Ref 12, 28) have been made on improving paints and beads and on developing completely different marking systems (e.g., buttons, raised markers, thermoplastic materials, and grooved stripes). These investigations have been initiated to (1) obtain improved day or night visibility; (2) extend service life, thereby reducing costs; (3) develop more efficient operations; (4) reduce slipperiness; (5) conform to health, safety, or environmental restraints; or (6) produce a combination of the preceding.

New Marking Paints

Numerous studies have been conducted on traffic paints based on resins other than those (such as alkyds) using drying oils. These included water-emulsion, hydrocarbon, epoxy, and polyvinyl toluene resin systems. In such studies (Ref 28, 63), alkyd paints performed as well as or better than other resin variations. The water-emulsion paints were found to have limited durability under heavy road traffic, but were quite suitable for runways (Ref 27). Their durability seems greater on textured than on smooth surfaces because of less contact between tires and paint. Investigations are being conducted to decrease the drying time of water-emulsion paints. In another study to develop a low solvent traffic paint, a fast-drying 100% solids epoxy is being investigated by the Federal Highway Administration (Ref 62). The proper embedment of glass beads in a very fast-setting paint is more of a problem than in slower-setting paints.

In a pigment study (Ref 28), a white modified alkyd paint containing 40% titanium dioxide performed as well as the same paint with 60% titanium dioxide and at less cost. Barium metaborate did not prevent yellowing of this paint. Substitution of lead silico-chromate for chrome yellow in a standard yellow traffic paint was not acceptable because of the resulting lemon coloration; however, durability was not affected.

A laboratory and field study (Ref 64) examined the performance of organic pigments in yellow alkyd and chlorinated rubber traffic paints as replacement for lead chromate because its use may be curtailed

due to health or environmental factors. In this test, the performance of the alternative yellow organic pigments, as measured by color change under the various exposure conditions, was found to be at least as good as that of lead chromate. In general, the monoazo (Hansa or modified Hansa) and the isoindolinone-pigmented formulations had less color change than the disazo (diarylide) pigmented formulations. The laboratory and field tests correlated well.

In studies of surface treatments prior to painting (Ref 49, 63, 65), it was found that neither acid etching nor special primers increased the durability of traffic paint on either asphaltic or portland cement concrete pavements, regardless of the age of the surface. Neither did preheating the paint before application. Results of a study (Ref 66) in which portland cement concrete surfaces were treated with a 50-50 mixture of boiling linseed oil and mineral spirits to increase paint adherence indicated that such treatment significantly improved paint adherence. Another study (Ref 67) showed paint performance on a portland cement concrete pavement to be improved by use of a primer with linseed oil, antispalling compound.

Hot-applied traffic paints have been studied (Ref 68-71) to determine whether the curing time can be greatly reduced so that lane closures, traffic control, and related costs in keeping vehicles from tracking the fresh paint would be minimized. Curing times of 30 seconds to 3 minutes have been achieved in this manner. The standard unheated paint generally performed better than the hot-applied paints (Ref 72), although differences were slight. Bead retention is more of a problem with hot-applied paints (Ref 68, 70). Plasticized melted sulfur and microwave energy (Ref 73) have been used to produce rapid paint drying, but these were impractical. A rapidly drying paint is not normally required for marking runways, so it is seldom used, particularly since rapid curing is often accompanied by loss of flexibility.

A study (Ref 72) was conducted to investigate the feasibility of adopting a bioluminescent or chemiluminescent system for use in a highway marker for wet-night lane delineation. From this study, which included a literature survey, theoretical evaluation, and limited laboratory testing of seven systems, chemiluminescent reaction of siloxene derivatives was recommended for further research because it can probably be placed in a solid matrix and activated by rainwater diffusion through a bed of solid oxidizer. Also, it is cheaper and more easily adapted to highway use than are the other systems.

Thermoplastic Pavement Striping Materials

Much laboratory and field research work (Ref 48, 74-78) has been conducted on hot-extruded thermoplastic striping materials that are applied at about 1/8-inch thickness and reflectorized with glass beads. Thinner stripes (e.g., 60 to 90 mils) are spray-applied (Ref 74, 76, 78). Important findings in these studies were:

1. Performance is better on asphaltic than on portland cement concrete pavement and on old rather than new portland cement concrete (Ref 74, 75).

2. Thermoplastic materials reflectorized with glass beads provide considerably more delineation when wet than painted stripes because the thicker plastic stripes usually protrude above the water film (Ref 75, 77).

3. Thermoplastic stripes are generally more abrasion-resistant than traffic paints (Ref 76).

4. Stripes applied over very smooth pavement failed more rapidly than those applied over rougher pavements (Ref 48).

5. To compare economically with painted stripes, thermoplastics must be in an area of heavy traffic (Ref 74, 75).

6. Unremoved layers of old paint adversely affect the bonding of thermoplastic striping to pavements (Ref 74).

7. Snowplow blades can dislodge thermoplastic striping (Ref 48, 74).

Thermoplastic pavement markings have not been used to any appreciable extent on runway pavements because such pavements receive relatively little traffic and centerline deterioration is related to rubber deposition. Both of these considerations make them uneconomical when compared to marking paints on airfield pavements. Also, because of their relatively great thickness, they do not retain the pavement texture and, thus, have less skid resistance.

Tapes

A variety of reflectorized and unreflectorized tapes (glue-down plastic stripes) have been marketed primarily for use as crosswalks and stop lines on bituminous pavements in high-density urban areas (Ref 12, 27). They do not provide the durability of painted markings, mainly because of poor adhesion to pavements, particularly portland cement concrete pavements. Thus, they are usually employed as temporary or semipermanent markings. Their use on airfield runways has the same limitations as those of thermoplastic markings.

Raised Pavement Markers

The use of both reflective and nonreflective raised markers for roadway lane delineation has been investigated many times (Ref 38, 54, 79-84). On California freeways (Ref 79), white, clean, ceramic

markers provide good daytime visibility and supplement the red-clear cube corner reflective markers at night when wet. However, in dry weather, they usually provide little nighttime delineation because of pitting and traffic staining. Ceramic wedges behaved similarly (Ref 85). Their lives may be in excess of 10 years.

Reflectance of cube-corner reflective markers is rapidly reduced after installation and may be reduced to about 1/20 to 1/50 of the original value within a few months due to surface abrasion (Ref 79). This level, however, is quite adequate and remains fairly constant thereafter. The markers reflect best when wet, the time when most needed. Because of their poor daylight visibility, they are always used in conjunction with painted markings or ceramic buttons. Even at night, overhead lighting diminishes their effectiveness (Ref 38). While the first raised reflectorized markers were readily damaged by snowplows, newer forms with stronger metal castings have been developed that are snowplowable (Ref 80-83).

Tests (Ref 84) were conducted to determine the usefulness of reflective markers in improving runway threshold and centerline identification at small airports because they are cheaper than electrical lights, are efficient, and are easy to install. During hours of darkness, such markers were found to be more effective in indicating the centerline than painted markings, but less effective in indicating the threshold than were threshold lights. The effectiveness of the markers is related to the intensity, location, and aiming of the aircraft landing lights in relation to the line of sight of the pilot. Shock to the nosewheel when the aircraft rolled over the markers was considered to be within acceptable limits. Although inexpensive and easy to install and maintain, the markers were not considered an effective replacement for either the centerline or the threshold lights. On runways serving heavy aircraft, the raised reflective marker would be rapidly damaged by impact of wheels.

Electrically powered and radioluminescent markers have also been studied. In each case, a practical system would be too costly to put into operational service. Radioluminescent markers would require very large quantities of radioactive gases, and electrically powered markers would require wiring the pavement.

Grooved Lines

Studies (Ref 86-88) have been conducted with grooved stripes for increased marking of wet-night visibility on roadways. Various grooving patterns have been used with beaded paint and raised reflectors. The reflector-groove combination was the most promising. Grooved pavements are the least vulnerable to rubber deposit buildup and traffic polishing (Ref 56). Dirt accumulation does appear to be a problem, however (Ref 87).

Cost Comparisons

Because of the many differences involved in pavement marking operations, it is difficult to reach a realistic estimate of life cycle costs for markings and even more so to compare the relative life cycle costs of different types of markings. These differences include (1) type of marking (numbers, centerlines, crosswalks, etc.), (2) amount of marking to be done, (3) type and magnitude of traffic (aircraft, urban traffic, freeway traffic, etc.), (4) environmental forces (temperature, precipitation, etc.), (5) contract versus in-house marking, (6) surface preparation requirements, and (7) quality of marking operation. One gallon of specification airfield marking paint (e.g., TT-P-85 or TT-P-1952) when applied at 15 mils wet film thickness will cover about 100 sq ft. This corresponds to about 33 lineal feet of 3-foot-wide runway centerline striping or 300 lineal feet of 4-inch-wide highway striping. A typical cost figure for such highway striping is $0.022/lineal ft, but costs may be much higher or lower (Ref 78, 86, 89).

Thermoplastic markings are generally more economical than painted traffic markings on crosswalks, stop lines, and other areas of heavy traffic, but the two systems are relatively comparable in cost in other locations (Ref 78, 89). In another study (Ref 86), life cycle traffic marking costs were found to be far more economical per lineal foot by conventional painting ($53 per year), than by grooved lines ($83 per year), or raised markers ($95 per year). To date, the marking of airfield pavements with conventional marking paints has proven to be the most economical system, but the search for methods of reducing such costs is continuing.

MARKING PRACTICES

Currently Used at Civil Airports

Several metropolitan and general aviation airports were contacted to determine commonly used runway marking practices and the effect of climate and size (traffic) on these practices. Some of the large commercial airports also controlled the operations of smaller airports so that the effect of traffic could readily be determined at such locations. Large suppliers of marking paints for airports were also contacted for supporting information.

Findings of the airport survey are summarized in Table 6. The effect of climate on airfield markings seemed to be very slight; therefore, different or more frequent maintenance procedures were not required. The chief effect was in restricting the time of painting to that portion of the year with warm weather.

Rapid drying times are generally not required for paints because the runways can be made accessible. Kennedy and La Guardia airports

have used paints with 1-minute drying times because of limited access to their runways. Several airport operators expressed preference for a medium to long drying time for better bonding of glass beads.

While most airports are using an alkyd paint conforming to Federal Specification TT-P-85, several are starting to use a latex paint (TT-P-1952). This trend can be expected to continue in the future. While latex paints have less durability under traffic, this has not proved to be an important factor for runways. Most airport operators and their staffs were not familiar with Federal Specification paints, and an effort to correct this deficiency is desirable. Present plans by the General Services Administration to have ASTM change its present federal specification to a performance specification for local purchase may alleviate this problem.

Deposition of rubber was an important factor on pavements serving heavy aircraft, but not on those serving light aircraft. Many different methods were used for removing the rubber. Water blasting seems to be replacing chemical cleaning because of costs and health, safety, and environmental hazards. No significant differences were noted in either the rate or mechanism of deterioration of painted markings between airfields serving aircraft with low pressure (commercial) tires and those serving aircraft with high pressure (military) tires (Ref 90).

Several large airports do not reflectorize their painted markings with glass beads because "they have excellent lighting systems." A few of the airport operators that do not reflectorize markings complained of reduced skid resistance and rapid loss of beads from reflectorized markings. Some were concerned about reduced skid resistance on unreflectorized markings. None of those with reflectorized markings reported such problems.

Most of the large airports had their own marking facilities. The one utilizing a contractor had services available 12 hours after calling.

The airport operators were generally satisfied with their present maintenance procedures. It is interesting to note that despite the many differences in marking practices, all stated that they followed the FAA recommendations.

Recommended

This section was prepared to present in brief form a set of recommended practices for insuring runways and taxiways achieve the painting of numbers, markings, and stripes on their properly prepared surfaces in accordance with written specifications, at locations shown on plans or specified by the engineer, and in a manner that achieves maximum operational life with satisfactory service to aircraft utilizing the facilities at a minimum expenditure of funds. Specific FAA recommendations can be found in Item P-620, Runway and Taxiway Painting, of Reference 91.

Materials. On asphaltic pavements and on all pavements at locations where pollution of air by organic solvents is considered a problem, TT-P-1952 acrylic water-emulsion marking paint should be used. On other pavements (i.e., portland cement concrete) either TT-P-1952 or TT-P-85 airfield marking paint should be used. Either paint may be used with or without reflective media. Whichever paint is used, it should be determined that it conforms to its specification requirements. Two 1-quart samples of the paint should be retained for later reference should problems arise.

When reflective paint is specified, spherical glass beads conforming to the specification requirements of TT-B-1325, Type III (high index of refraction), Gradation A (coarse drop-on) should be used. With TT-P-85 granules conforming to TT-G-490, Type I, may be used in place of beads.

While it is economical to purchase striping materials in large quantity (Ref 92), this is a good practice only if proper storage conditions are achieved. Materials should be stored inside a building out of the weather. Paint should be procured, stored, and used so that none is stored for more than 1 year. It should not be stored in 55-gallon drums if the drums are to be reopened frequently to remove small quantities, as this may greatly reduce storage life. Special care must be taken to keep beads dry at all times; beads stuck together in a large mass should be discarded rather than trying to reclaim them.

Surface Preparation. Airfield pavements must be satisfactorily cured (at least 2 weeks curing for portland cement concrete and 3 weeks for asphaltic pavements) before striping. A well-textured surface is desired for maximum bonding of paint.

Immediately before application of paint, the existing surface must be dry and completely free of dirt, grease, oil, laitance, and other foreign matter that would reduce the bonding of the paint to the pavement. The loose materials can be readily removed by sweeping or blowing. Materials remaining after this treatment must be removed by scrubbing with a water solution of trisodium phosphate (10% by weight) or an equally effective detergent solution. After scrubbing, the solution should be removed from the pavement with water.

Before painting over existing markings, all the loose marking must be removed by water blasting or mechanical means. It is best not to repaint an existing marking after five coats have been applied to the pavement because of accelerated deterioration and reduced skid resistance. In painting over existing markings, especially when applying a water-emulsion paint such as TT-P-1952, all loose chalk must be removed from the old painted surface.

Existing markings or stripes that are to be abandoned are best removed by high pressure water blasting.

Layout and Alignment. On sections of pavement where no previously applied figures, markings, or stripes are available to serve as a guide, suitable layouts and lines of the proposed stripes should be spotted sufficiently in advance that they can be approved by the responsible engineer before paint is applied.

Application. All equipment for accomplishing the required work, including that necessary for preparing the existing surface and application of paint, should be approved by the responsible engineer before any work is begun. Striping is usually accomplished with a self-propelled or towed mechanical marking machine, and numbers and other smaller markings are done with auxiliary manual equipment. Support equipment for mixing paint and testing spray equipment must also be accessible. The mechanical marker must contain spray equipment that will produce smooth, properly aligned, paint stripes of uniform required thickness and width and with clear-cut edges (without runs or spatters). When the marking is to be reflectorized, apparatus for dispensing glass beads (or granules) into the wet paint must be a part of the mechanical marker. Suitable adjustments should be provided to control the rate of application of paint and beads.

The paint and beads or granules (if reflectorized) should be applied uniformly at the rates called for in the specifications:

1. Paint
   TT-P-85: 100 to 110 sq ft/gal
   TT-P-1952: 100 to 150 sq ft/gal

2. Beads
   TT-B-1325, Type III, Gradation A: 10 lb/gal

3. Granules
   TT-G-490, Type I: 1.7 lb/gal

These application rates should be verified before striping by checking the metering of the marking equipment and the wet and/or dry film thickness. The spreading rates correspond to about 15 mils wet and 7 to 8 mils dry film thickness. The rate can be verified further by measuring the area painted and figuring the volume of paint used by retained empty containers. The glass bead (or granule) dispensing rate can also be determined from the amount used, and the uniformity of distribution can be checked visually. Paints should not be thinned before application as this would affect the rate of application and depth of bead embedment. All painting operations should be in accordance with the manufacturer's or specification instructions. Should it be necessary to apply any paint by brush or roller to an asphaltic pavement, the surface should receive two coats, with the second coat applied after the first coat has thoroughly dried. This will reduce the possibility of bleeding.

Paint application should not occur at times of excessively high winds (to prevent irregular paint spray and deposition of dust onto wet paints), high humidity (to prevent improper curing), or low temperature (above 40F for TT-P-85 and above 50F for TT-P-1952) to permit proper curing in a reasonable time. After paint application, all markings should be protected from damage (e.g., vehicle tracking) until curing is complete.

RECOMMENDED FURTHER RESEARCH

Four important areas of research and investigation are recommended for prompt action to improve existing practices or meet new requirements:

1. The use of more flexible isophthalate alkyd resins rather than the currently used ortho-phthalate alkyd resins in marking paints. Such a paint formulation might have sufficient flexibility to perform well on asphaltic pavements without a sacrifice in curing time or other important properties.

2. The newer types of water-emulsion marking paints in anticipation of tighter restrictions on the emission of organic solvent vapors from paints. This should include those resins based on drying oils and, if necessary, methods to accelerate their curing. Methods of increasing the durability of latex marking paints should be investigated.

3. The use of high solids (85% or higher) marking paints in anticipation of tighter restrictions on the emission of organic solvent from paints. This should include a study of the relationship between drying time and flexibility.

4. The use of thinner paint films (e.g., 10 mils wet) and fewer appropriately graded glass beads on airfield markings. Such a practice, if practical, would result in (a) saving of application costs, (b) reduced rates of deterioration, and (c) better skid resistance.

CONCLUSION

While practices presently used for marking airfield pavements are adequate, improved materials or procedures can be developed that would reduce maintenance costs and meet anticipated stringent requirements imposed by health, safety, or environmental considerations.

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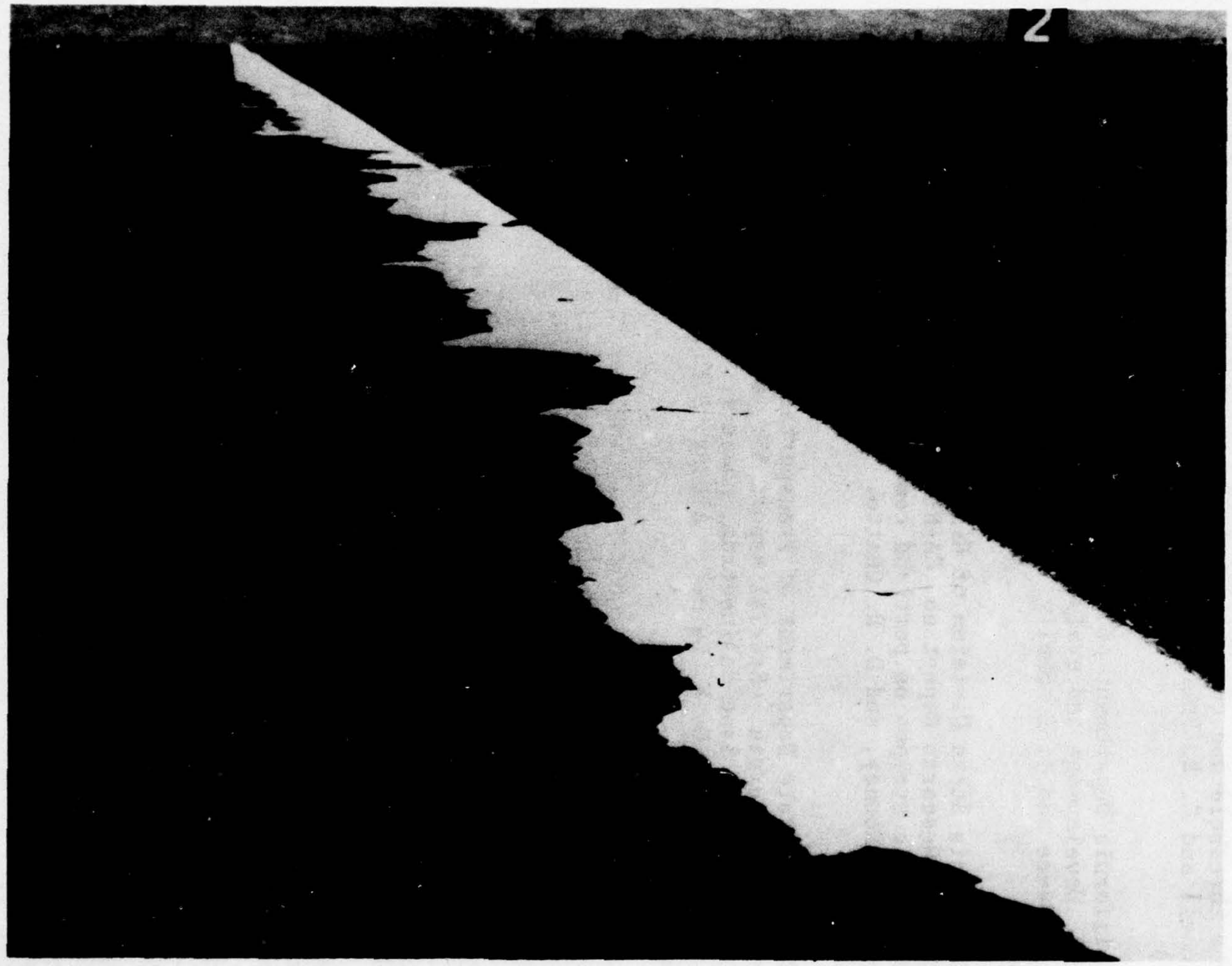

Figure 1. Loss of runway striping and slurry seal initiated by edge cracking.

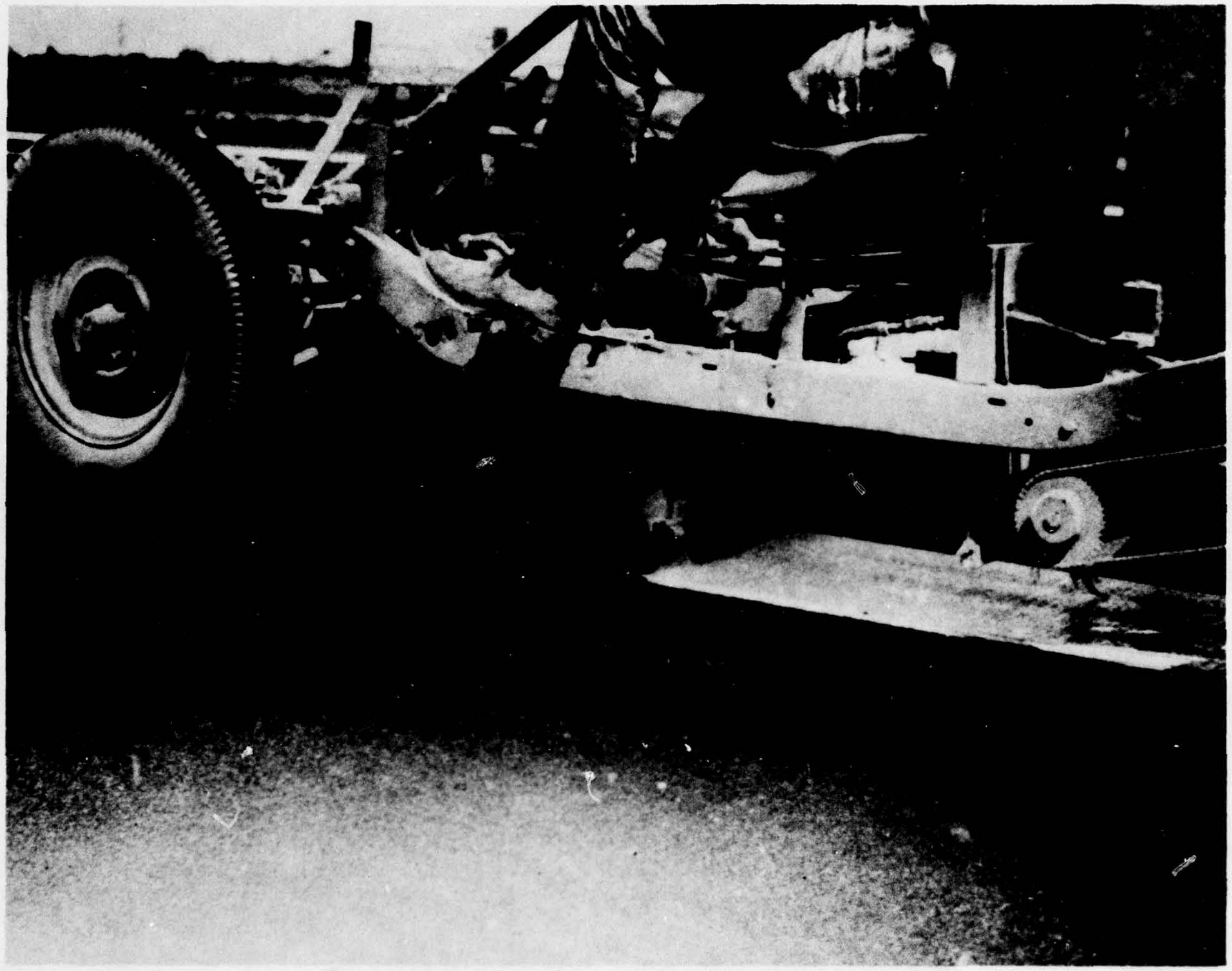

Figure 2. Striping of airfield runway.

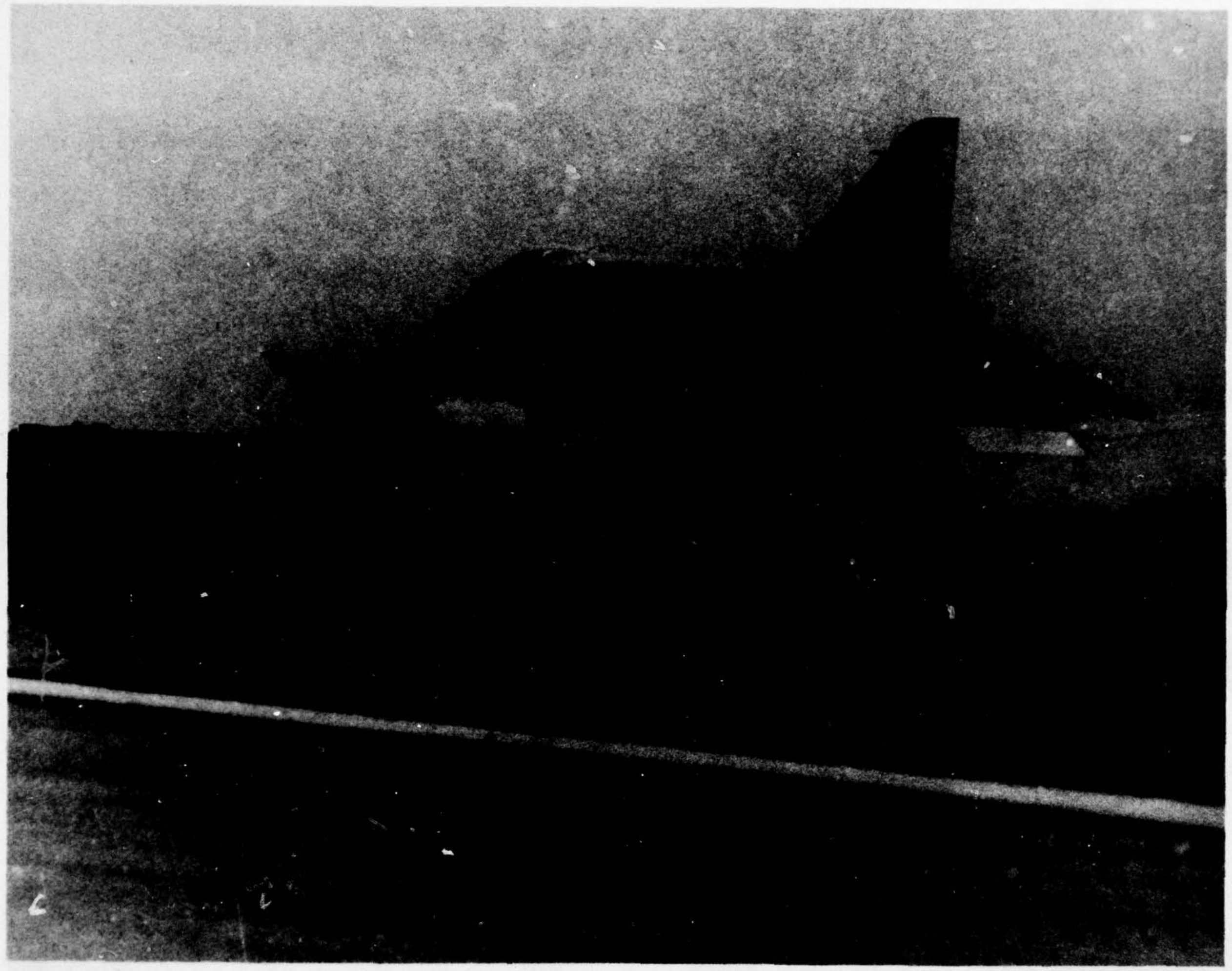

Figure 3. Deposition of rubber on runway by high speed aircraft.

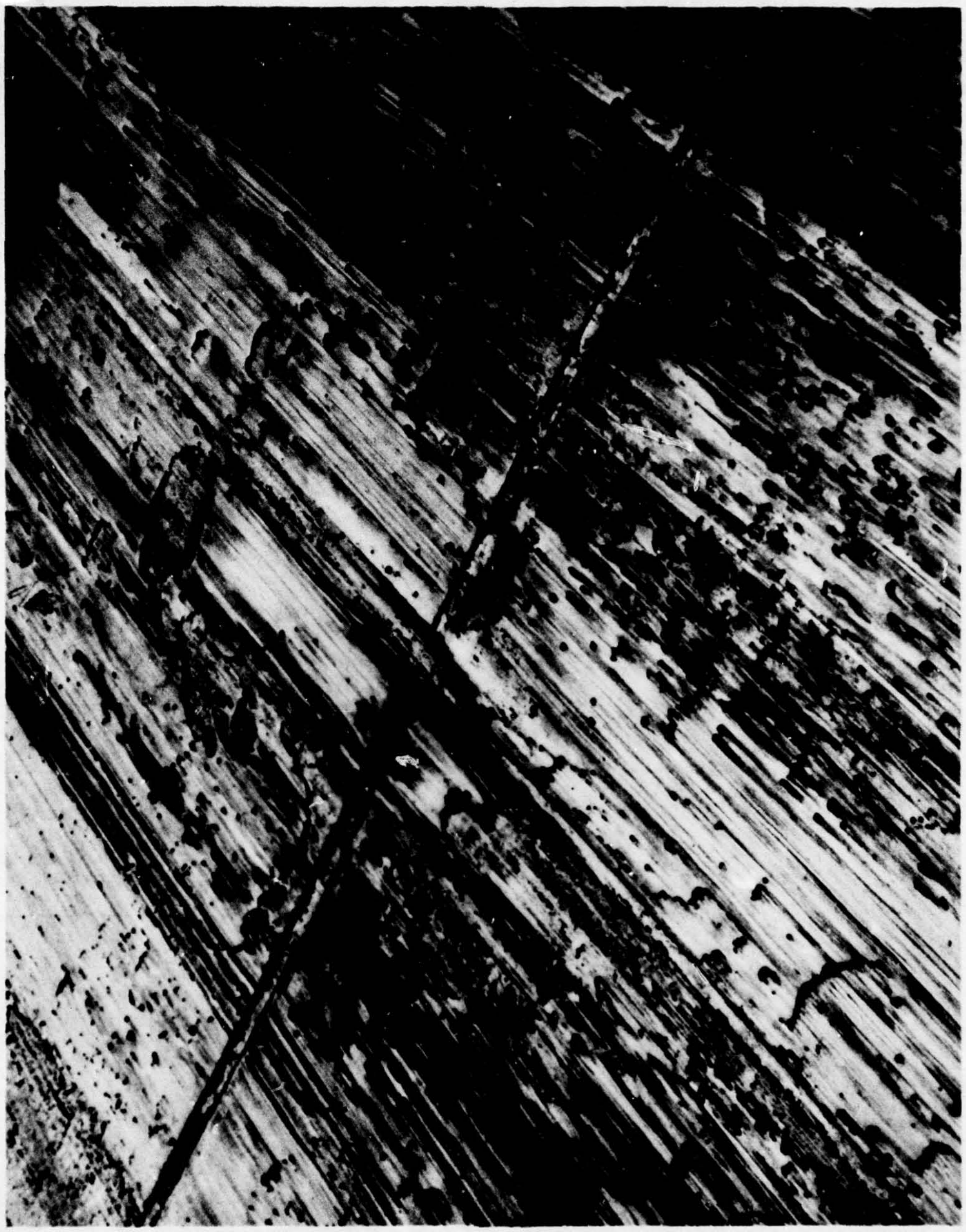

Figure 4. Buildup of rubber deposits on striped runway.

Table 1. Oil Length of Paints

Oil Length	Alkyd[a] (% phthalic anhydride)	Varnish[b] (gal oil/100 lb resin)
Short	40 to 50	below 15
Medium	30 to 40	15 to 30
Long	20 to 30	above 30

[a]Taken from Reference 14, page 280.
[b]Taken from Reference 15, page 6.

Table 2. Federal Specification Pavement Marking Paints Suitable for Use on Airfield Pavements

Federal Specification	Available Colors	Volatile Vehicle (solvent)	Nonvolatile Vehicle (resin)	Maximum Drying Time (min)	Spreading Rate or Wet Film Thickness	Reflectorization		
						Material	Specification	Application Rate
TT-P-85	white and yellow	Rule 66 organic solvent[a]	wide choice	40	105 ±5 sq ft per gal	glass spheres glass granules	TT-B-1325 Type III, Gradation A TT-G-490, Type I	10 lb per gal 0.15 ±0.1 lb per 100 sq ft
TT-P-110	black	Rule 66 organic solvent[a]	wide choice	30 (Type I) 4 (Type II)	15 mils wet			
TT-P-115	white and yellow	Rule 66 organic solvent[a]	Type I (alkyd) Type II (vinyl toluene-butadiene) Type III (chlorinated rubber-alkyd)	60 30 15	15 mils wet	glass spheres	-	6 lb per gal
TT-P-1952	white and yellow	water	acrylic	75	100 to 150 sq ft per gal	glass spheres	TT-B-1325, Type III, Gradation A	10 lb per gal

[a]Former Los Angeles Air Pollution Control District rule limiting amounts of photochemically reactive solvents.

Table 3. Marking Paints Sold by GSA

Federal Specification	No. of Gallons		
	1976	1977	1978 (projected)
TT-P-85	308,686	313,555	237,275
TT-P-1952	–	61,150	73,720
TT-P-110	16,100	16,718	17,014
TT-P-115	227,629	192,069	245,800
TT-P-87	12,720	14,185	13,895

Table 4. ASTM Tests for Traffic Paints

Test Procedure	Test Type	ASTM Designation
No Pick-Up Drying Time of Traffic Paint	laboratory	D1155
Degree of Bleeding of Traffic Paint	laboratory	D969
Degree of Settling of Traffic Paint	laboratory	D869
Roundness of Glass Spheres	laboratory	D1155[a]
Sieve Analysis of Glass Spheres	laboratory	D1214[a]
Road Service Tests on Traffic Paints	field	D713
Abrasion, Erosion, or Both	field	D821[b]
Degree of Chipping of Traffic Paints	field	D913[b]
Degree of Bleeding of Traffic Paints	field	D868[b]

[a]In Annual Book of ASTM Standards, vol 20 of Reference 22; other seven are in vol 27.

[b]Photographic standards are given to permit uniform rating.

Table 5. Types of TT-B-1325 Spherical Glass Beads

Bead Type	Index of Refraction	Glass Composition	Available Gradations
I	low (1.50-1.64)	High quality crown glass of soda lime type. Not less than 65% silica or more than 3% lead.	A (coarse drop-on) B (fine premix) C (fine drop-on)
II	medium (1.65-1.89)	High quality glass. Not more than 3% lead.	A (coarse drop-on)
III	high (1.90 min)	High quality, lead-free glass.	A (coarse drop-on) B (fine drop-on)

Table 6. Summary of Data on Civil Airport Marking Practices

[All airports used FAA Advisory Circular 150/5370-10]

Condition	Civil Airport Marking Practices for –							
	Commercial Airport					General Aviation Airport		
Frequency of Operations	2,200/day	2,000/day	900/day	550/day	200/day	Heavy	Medium	Light
Type of Climate	hot summer cold winter	warm summer mild winter	hot summer mild winter	mild summer cold winter	warm summer cold winter	warm summer mild winter	warm summer cold winter	warm summer mild winter
Type of Paint Used	Alkyd TT-P-85	Alkyd TT-P-85	Latex TT-P-1952	local supplier	Alkyd TT-P-85	Alkyd TT-P-85	local supplier	local supplier
Special Striping Practices	white markings outlined with black paint[a]	none	use latex paint	minimal surface preparation	none	none	none	none
Method of Making Runway Available for Marking	close runway[b]	close runway	close runway	close runway	usually night striping	close runway	close runway	close runway
Frequency of Painting	1 - 2 times per year	3 times per year	3 times per year	3 times per year	once a year	once a year	every 2 years	every 4 years
Reason for Paint Failure (reason for restriping)	rubber deposits; paint loss[c]	rubber deposits	paint loss	rubber deposits	rubber deposits; paint loss[c]	paint loss	paint loss[c]	paint loss
Reflectorized (R) or Unreflectorized (UR) Paint Used	R	UR	R	UR	UR	R	R	R
In-House (IN) or Contractor (C) Applied	C	IN	IN	IN	IN	C	C	C
Frequency of Rubber Removal	1 - 2 times per year	3 times per year	3 times per year	3 times per year	–	–	–	–
Method of Rubber Removal	water blasting	chemical	water blasting	chemical, water blasting, and mechanical	painted over	painted over	painted over	painted over

[a]Special equipment applies white and black paint and glass beads to portland cement and asphaltic runways in one pass.

[b]Gate areas and taxiways are painted at night.

[c]Chemicals, sand, and snow plowing during winter accelerates paint erosion.

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NAVACTDET PWO, Holy Lock UK

NAVAEROSPREGMEDCEN SCE, Pensacola FL

NAVAL FACILITY PWO, Barbados; PWO, Cape Hatteras, Buxton NC; PWO, Centerville Bch, Ferndale CA; PWO, Guam

NAVAVIONICFAC PWD Deputy Dir. D/701, Indianapolis, IN

NAVCOASTSYSLAB Code 423 (D. Good), Panama City FL; Code 715 (J. Mittleman) Panama City, FL; Code 715 (J. Quirk) Panama City, FL; Library Panama City, FL

NAVCOMMAREAMSTRSTA Code W-602, Honolulu, Wahiawa HI; PWO, Norfolk VA; PWO, Wahiawa HI; SCE Unit 1 Naples Italy

NAVCOMMSTA Code 401 Nea Makri, Greece; PWO, Adak AK; PWO, Exmouth, Australia; PWO, Fort Amador Canal Zone

NAVCOMMUNIT Cutler/E. Machias ME (PW Gen. For.)

NAVEDTRAPRODEVCEN Tech. Library

NAVEDUTRACEN Engr Dept (Code 42) Newport, RI

NAVENVIRHLTHCEN CO, Cincinnati, OH

NAVEODFAC Code 605, Indian Head MD

NAVFAC PWO, Lewes DE

NAVFACENGCOM Code 043 Alexandria, VA; Code 044 Alexandria, VA; Code 0451 Alexandria, VA; Code 0453 (D. Potter) Alexandria, VA; Code 0454B Alexandria, Va; Code 046; Code 0461D (V M Spaulding) Alexandria, VA; Code 04B3 Alexandria, VA; Code 04B5 Alexandria, VA; Code 101 Alexandria, VA; Code 10133 (J. Leimanis) Alexandria, VA; Code 1023 (M. Carr) Alexandria, VA; Code 1023 (T. Stevens) Alexandria, VA; Code 104 Alexandria, VA; Code 2014 (Mr. Taam), Pearl Harbor HI; Morrison Yap, Caroline Is.; PC-22 (E. Spencer) Alexandria, VA

NAVFACENGCOM - CHES DIV. Code 101 Wash, DC; Code 403 (H. DeVoe) Wash, DC; Code 405 Wash, DC; Contracts, ROICC, Annapolis MD; Scheessele, Code 402, Wash, DC

NAVFACENGCOM - LANT DIV.; Code 10A, Norfolk VA; Eur. BR Deputy Dir, Naples Italy; RDT&ELO 09P2, Norfolk VA

NAVFACENGCOM - NORTH DIV. AROICC, Brooklyn NY; CO; Code 09P (LCDR A.J. Stewart); Code 1028, RDT&ELO, Philadelphia PA; Code 111 (Castranovo) Philadelphia, PA; Code 114 (A. Rhoads); Design Div. (R. Masino), Philadelphia PA; ROICC, Contracts, Crane IN

NAVFACENGCOM - PAC DIV. Code 402, RDT&E, Pearl Harbor HI; Commander, Pearl Harbor, HI

NAVFACENGCOM - SOUTH DIV. Code 90, RDT&ELO, Charleston SC; Dir., New Orleans LA; ROICC (LCDR R. Moeller), Contracts, Corpus Christi TX

NAVFACENGCOM - WEST DIV. 102; 112; AROICC, Contracts, Twentynine Palms CA; Code 04B; O9P/20; RDT&ELO Code 2011 San Bruno, CA

NAVFACENGCOM CONTRACT AROICC, Point Mugu CA; AROICC, Quantico, VA; Code 05, TRIDENT, Bremerton WA; Dir, Eng. Div., Exmouth, Australia; Eng Div dir, Southwest Pac, Manila, PI; OICC, Southwest Pac, Manila, PI; OICC/ROICC, Balboa Canal Zone; ROICC (Ervin) Puget Sound Naval Shipyard, Bremerton, WA; ROICC (LCDR J.G. Leech), Subic Bay, R.P.; ROICC AF Guam; ROICC LANT DIV., Norfolk VA; ROICC Off Point Mugu, CA; ROICC, Diego Garcia Island; ROICC, Keflavik, Iceland; ROICC, Pacific, San Bruno CA

NAVHOSP LT R. Elsbernd, Puerto Rico

NAVMAG SCE, Guam

NAVMIRO OIC, Philadelphia PA

NAVNUPWRU MUSE DET Code NPU-30 Port Hueneme, CA
NAVOCEANO Code 1600 Bay St. Louis, MS; Code 3432 (J. DePalma), Bay St. Louis MS
NAVOCEANSYSCEN Code 5224 (R.Jones) San Diego CA; Code 6700, San Diego, CA; Code 7511 (PWO) San Diego, CA; SCE (Code 6600), San Diego CA
NAVORDSTA PWO, Louisville KY
NAVPETOFF Code 30, Alexandria VA
NAVPGSCOL LCDR K.C. Kelley Monterey CA
NAVPHIBASE CO, ACB 2 Norfolk, VA; Code S3T, Norfolk VA; Harbor Clearance Unit Two, Little Creek, VA; OIC, UCT ONE Norfolk, Va
NAVRADRECFAC PWO, Kami Seya Japan
NAVREGMEDCEN Code 3041, Memphis, Millington TN; PWO Newport RI; PWO Portsmouth, VA; SCE (D. Kaye); SCE (LCDR B. E. Thurston), San Diego CA; SCE, Camp Pendleton CA; SCE, Guam
NAVSCOLCECOFF C35 Port Hueneme, CA; CO, Code C44A Port Hueneme, CA
NAVSEASYSCOM Code 0325, Program Mgr, Washington, DC; Code OOC (LT R. MacDougal), Washington DC; Code SEA OOC Washington, DC
NAVSEC Code 6034 (Library), Washington DC
NAVSECGRUACT Facil. Off., Galeta Is. Canal Zone; PWO, Edzell Scotland; PWO, Puerto Rico; PWO, Torri Sta, Okinawa
NAVSHIPREPFAC SCE Subic Bay
NAVSHIPYD; CO Marine Barracks, Norfolk, Portsmouth VA; Code 202.4, Long Beach CA; Code 202.5 (Library) Puget Sound, Bremerton WA; Code 380, (Woodroff) Norfolk, Portsmouth, VA; Code 400, Puget Sound; Code 404 (LT J. Riccio), Norfolk, Portsmouth VA; Code 410, Mare Is., Vallejo CA; Code 440 Portsmouth NH; Code 440, Norfolk; Code 440, Puget Sound, Bremerton WA; Code 440.4, Charleston SC; Code 450, Charleston SC; L.D. Vivian; Library, Portsmouth NH; PWD (Code 400), Philadelphia PA; PWO, Mare Is.; PWO, Puget Sound; SCE, Pearl Harbor HI; Tech Library, Vallejo, CA
NAVSTA CO Naval Station, Mayport FL; CO Roosevelt Roads P.R. Puerto Rico; Engr. Dir., Rota Spain; Maint. Cont. Div., Guantanamo Bay Cuba; Maint. Div. Dir/Code 531, Rodman Canal Zone; PWD (LTJG.P.M. Motolenich), Puerto Rico; PWO Midway Island; PWO, Guantanamo Bay Cuba; PWO, Keflavik Iceland; PWO, Mayport FL; ROICC Rota Spain; ROICC, Rota Spain; SCE, Guam; SCE, San Diego CA; SCE, Subic Bay, R.P.; Utilities Engr Off. (LTJG A.S. Ritchie), Rota Spain
NAVSUBASE LTJG D.W. Peck, Groton, CT
NAVSUPPACT CO, Brooklyn NY; CO, Seattle WA; Code 4, 12 Marine Corps Dist, Treasure Is., San Francisco CA; Code 413, Seattle WA; LTJG McGarrah, Vallejo CA; Plan/Engr Div., Naples Italy
NAVSURFWPNCEN PWO, White Oak, Silver Spring, MD
NAVTECHTRACEN SCE, Pensacola FL
NAVWPNCEN Code 2636 (W. Bonner), China Lake CA; PWO (Code 26), China Lake CA; ROICC (Code 702), China Lake CA
NAVWPNSTA EARLE (Clebak) Colts Neck, NJ; Code 092, Colts Neck NJ; ENS G.A. Lowry, Fallbrook CA; Maint. Control Dir., Yorktown VA; PW Office (Code 09C1) Yorktown, VA
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NAVXDIVINGU LT A.M. Parisi, Panama City FL
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NCBU 411 OIC, Norfolk VA
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NSD SCE, Subic Bay, R.P.; Security Offr, Yokosuka, Japan
NTC Code 54 (ENS P. G. Jackel), Orlando FL; Commander Orlando, FL; OICC, CBU-401, Great Lakes IL
NUSC Code 131 New London, CT; Code EA123 (R.S. Munn), New London CT; Code TA131 (G. De la Cruz), New London CT
OCEANSYSLANT LT A.R. Giancola, Norfolk VA
ONR BROFF, CO Boston MA; Code 700F Arlington VA; Dr. A. Laufer, Pasadena CA

PHIBCB I P&E, Coronado, CA
PMTC Pat. Counsel, Point Mugu CA
PWC ACE Office (LTJG St. Germain) Norfolk VA; CO Norfolk, VA; CO, Great Lakes IL; CO, Oakland CA; Code 120, Oakland CA; Code 120C (Library) San Diego, CA; Code 128, Guam; Code 200, Great Lakes IL; Code 200, Guam; Code 200, Oakland CA; Code 220 Oakland, CA; Code 220.1, Norfolk VA; Code 40 (C. Kolton) Pensacola, FL; Code 400, Pearl Harbor, HI; Code 505A (H. Wheeler); Code 680, San Diego CA; Library, Subic Bay, R.P.; OIC CBU-405, San Diego CA; Utilities Officer, Guam; XO Oakland, CA
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